GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date May 4, 1966

Project Title: Scientific and Engineering Assistance on Mine Defense Problems

Project No.: A-937

Project Director: A. L. Bennett

Sponsor: Dept. of the Navy, Navy Purchasing Office

Effective: 4-26-66 Estimated to run until: 6-30-67

Type agreement: Contract No. N600(24)59885

Amount: $10,000 (estimated) *

Reports: Monthly Letter Reports
Final Technical Report

Contact Person: Navy Purchasing Office
Washington Navy Yard
Washington, D. C. 20390

Attn: Contracting Officer
(for admin. matters)

U. S. Navy Mine Defense Laboratory
Panama City, Florida

Attn: Dr. E. A. Hogge, Code 710
(for tech. matters)

* NO additional funds have been added to the contract at this time. Funding will come from A-874 pending the addition of funds to the contract to support this work.

Assigned to Physical Sciences Division

REPORT 300.A-937

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Report requirements are the same as A-531, A-770, A-874

R. E. Bryan

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date 12-11-67

PROJECT TITLE: Scientific and Engineering Assistance on Mine Defense Problems

PROJECT NO: A-937

PROJECT DIRECTOR: A. L. Bennett

SPONSOR: Dept. of the Navy, Navy Purchasing ~~On Mine Defense Problems~~ Office

TERMINATION EFFECTIVE: 12-11-67

CHARGES SHOULD CLEAR ACCOUNTING BY: All charges have cleared

Physical Sciences

REPORTS
300.A-937

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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

July 7, 1966

Department of the Navy
U. S. Navy Mine Defense Laboratory
Panama City, Florida

Attention: Dr. E. A. Hogge, Code 710

Subject: Monthly Progress Letter Report 2, Project A-937
"Scientific and Engineering Assistance on Mine Defense Problems"
Contract No. N600(24)-59885
Covering the Period from June 1 to June 30, 1966

Gentlemen:

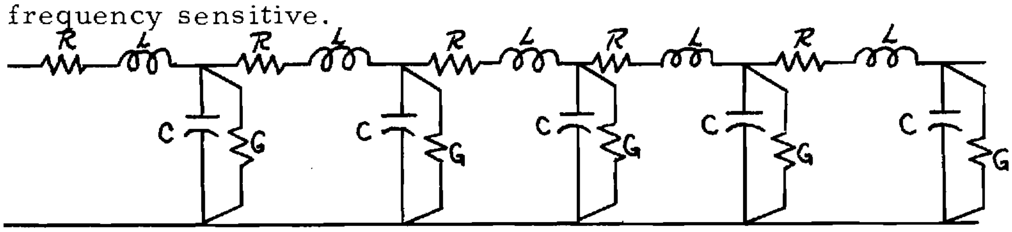
During this reporting period the analysis of the frequency-shift detection scheme has been completed indicating it is not a practical approach. The results of this work however have provided some insights into the general interrelations of parameters and practical parameter magnitudes. Therefore, it is now easier to estimate the potential of a proposed scheme and quantitatively evaluate its operation.

The basic concept of the proposed schemes is that of inducing a current in the mine wire through the mutual inductance of the wire and a driven search coil. Detection of the wire then reduces to some means of sensing the current induced in the wire. The major problem however is the relatively high impedance of the wire-circuit and the relatively low value of attainable mutual inductance.

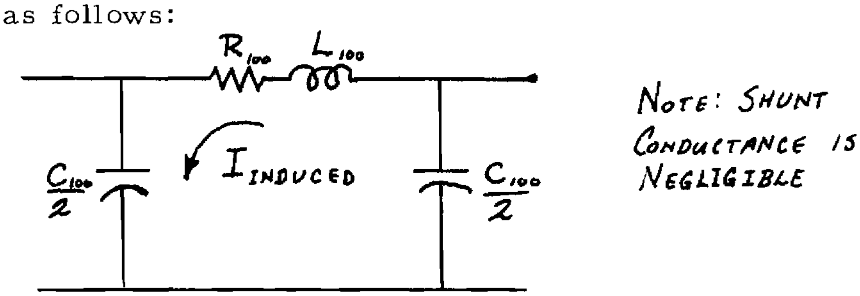
The wire-circuit is easily visualized in the following manner. Consider a metal conductor or conductors surrounded by an insulating layer, submerged in sea water. At frequencies 1 MHz and less in sea water, the ratio

$$\frac{\omega \epsilon}{\sigma} < 10^{-3} \qquad \omega = 2\pi \text{ frequency}$$
$$\epsilon = \text{permittivity}$$
$$\sigma = \text{conductivity}$$

which demonstrates that displacement currents in water are negligible compared to conduction currents. Hence the wire can definitely be considered as a coaxial cable with the sheath being the sea water. The parameters of the cable then consist of series R and L, where R and L are determined primarily by the effective sea water sheath and shunt C and G depending on the insulation. Thus a length of wire submersed in sea water would have the following approximate equivalent circuit, where R and L are frequency sensitive.



As a first approximation to the line, a length of 100 meters is assumed and the total inductance, resistance and capacitance are lumped into a Pi equivalent as follows:



LUMPED EQUIVALENT of 100 METER LINE

Although we initially thought the series inductance would be negligible it has been found that this is not true and that above 65 kHz the inductive reactance predominates. In the figure, the current I induced is the current which must be detected.

The impedance of the insulated cable-sea water return combination is discussed by von Aulock.* A discrepancy was found in the equations for

*The electrical characteristics of a laminated coaxial cable with sea water return, by Wilhelm von Aulock. BuShips Minesweeping Branch T. M. No. 151, September 1950.

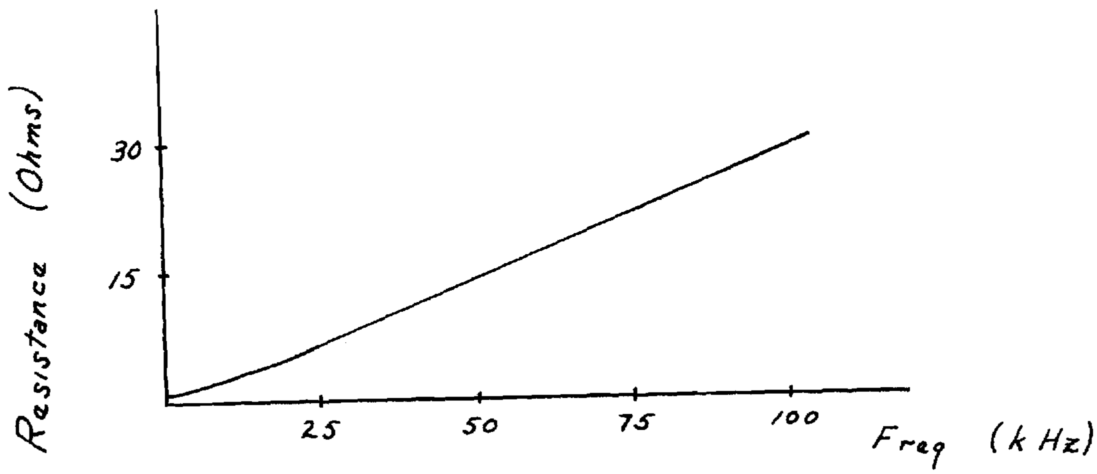
the $\overline{E}$ and $\overline{H}$ fields in water as they did not satisfy the boundry conditions. Therefore, these calculations were carried out from a slightly different approach in order to be assured that the results were correct. The corrected equations for $\overline{E}$ and $\overline{H}$ in the sea water return as developed are:

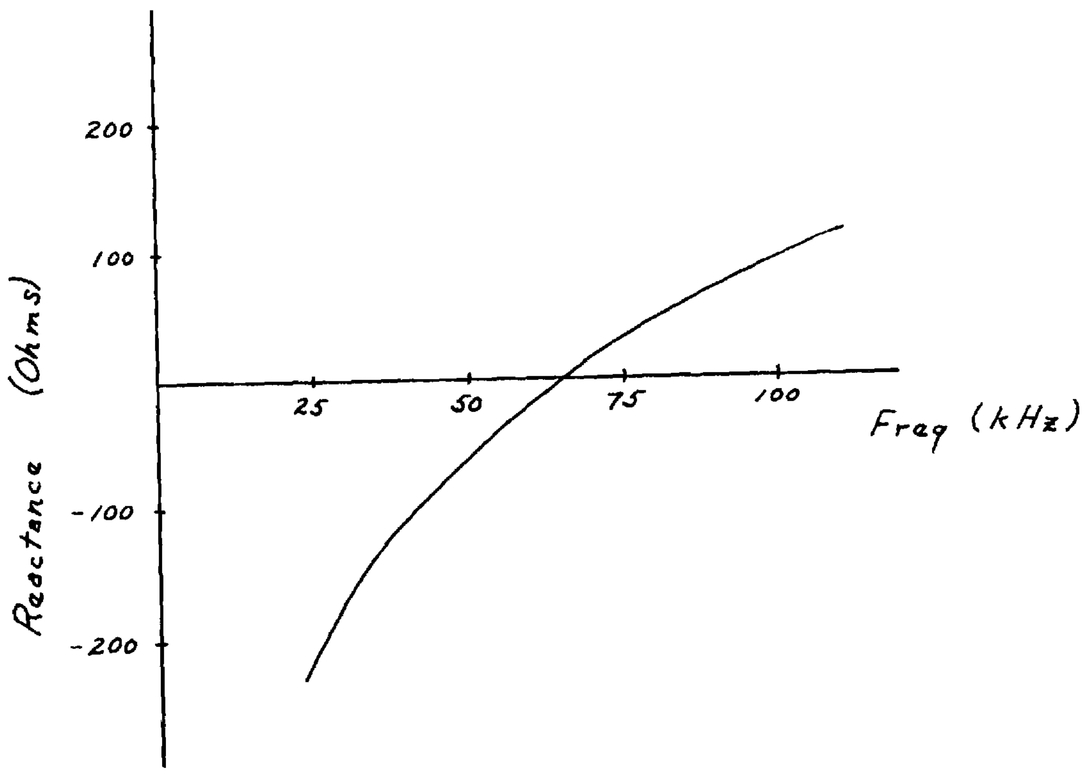
$$H_\phi = -\frac{I}{2\pi b_2} \; \frac{\mathrm{ker}'x + j\,\mathrm{kei}'x}{\mathrm{ker}'\left(\frac{b_2\sqrt{2}}{\delta}\right) + j\,\mathrm{kei}'\left(\frac{b_2\sqrt{2}}{\delta}\right)} \; e^{-j\omega t}$$

$$E_z = -\frac{I\sqrt{j}\,\sqrt{\omega\mu\sigma}}{2\pi b_2\,\sigma} \; \frac{\mathrm{ker}\,x + j\,\mathrm{kei}\,x}{\mathrm{ker}'\left(\frac{b_2\sqrt{2}}{\delta}\right) + j\,\mathrm{kei}'\left(\frac{b_2\sqrt{2}}{\delta}\right)} \; e^{-j\omega t}$$

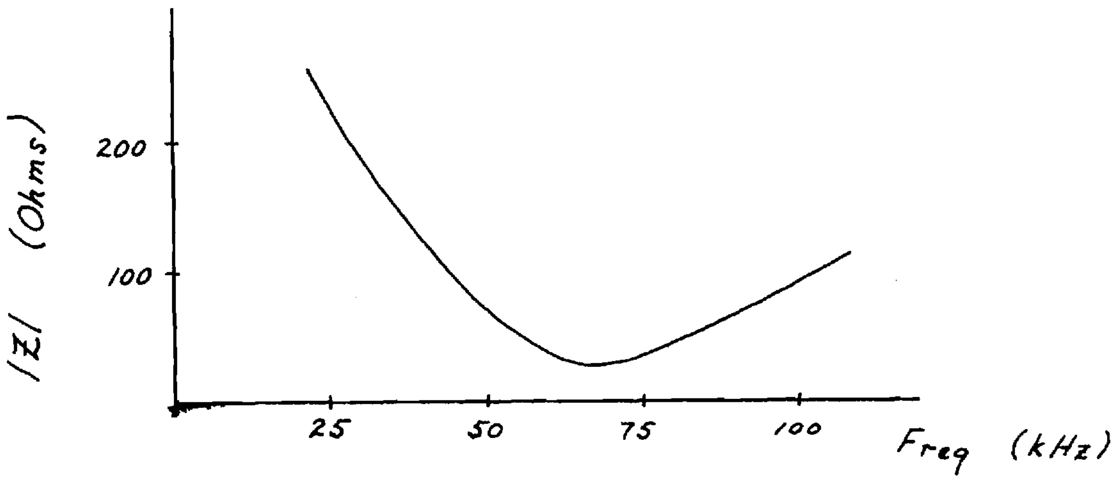
Next, rather than the energy approach to calculate R and L as was carried out by von Aulock, an impedance approach as proposed by Ramo & Whinnery* was used. Carrying through this development, we arrived at the identical final equations of von Aulock. Simple plots of the resistance and reactance of the transmission line equivalent circuit versus the frequency of the detection system are shown on page 4.

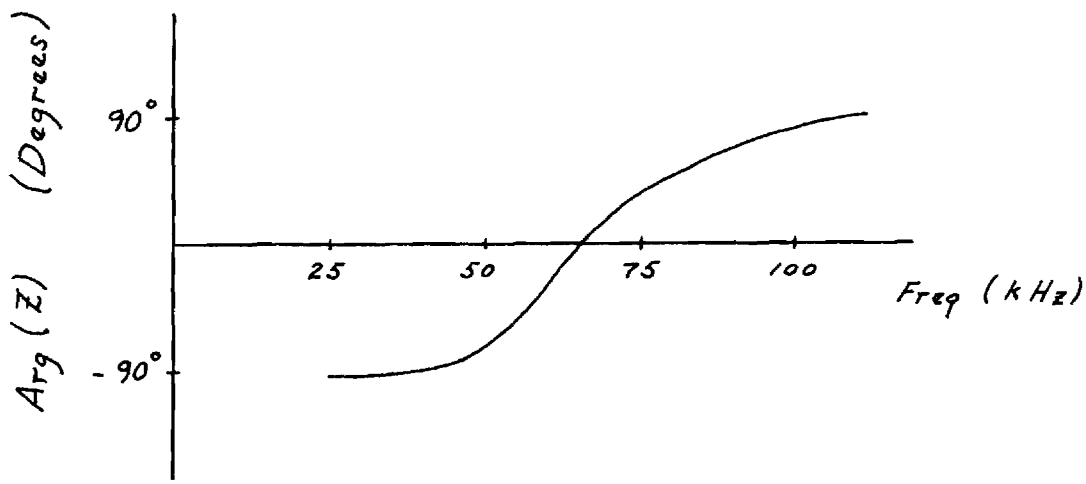
* "Fields & Waves in Modern Radio," 2nd Ed., Wiley & Sons, New York, 1953, p. 214.


Resistance (Ohms)
30
15
25
50
75
100
Freq (kHz)

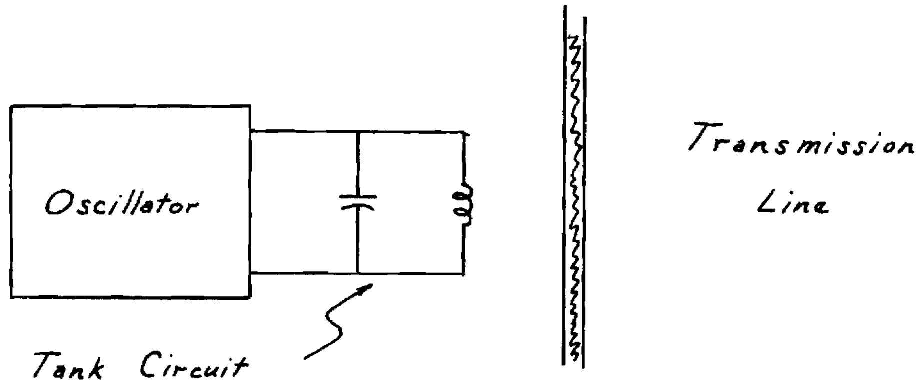

Reactance (Ohms)
200
100
-100
-200
25
50
75
100
Freq (kHz)

Somewhat more meaningful plots for later discussion would be magnitude and phase plots of the transmission line impedance.





A block diagram representation of the frequency-shift system is shown below.



The resonant frequency of the tank circuit is the frequency of the oscillator. The coil of the tank circuit is the primary detecting device. When the coil approaches the cable it couples inductively with the transmission line. Due to the mutual coupling, the impedance of the transmission line is reflected into the tank thereby decreasing the frequency of the oscillator.

The impedance of the transmission line reflects into the tank circuit as an impedance in series with the coil and this reflected impedance is given by:

$$Z_{ref} = \frac{(\omega M)^2}{Z_{TL}}$$

where M is the mutual inductance

ω is the radian frequency

Z_{TL} is the transmission line impedance

For a coil of reasonable size, M is approximately 0.3×10^{-6} henries. The self inductance may be varied somewhat without significantly affecting the mutual inductance, but 0.8×10^{-6} henries is a reasonable figure. Referring back to the magnitude plot of the transmission line impedance, the value of Z_{TL} at 50 kHz was chosen. This value was chosen because at this frequency the real part of the impedance was small and the imaginary part was large enough to cause a phase angle of approximately the same order of magnitude as the real part (Z_{TL} = 17.6 - j 29 ohms). The frequency shift of the oscillator is dependent on the imaginary part. When the values mentioned above were substituted into the formula, it was found that the magnitude of the reflected impedance differed from the magnitude of the impedance of the coil by approximately four orders of magnitude. This difference is too great to cause a significant change in the frequency of the oscillator. If the value of the self inductance is changed to decrease this difference, then the value of the capacitor to cause resonance is prohibitive. Therefore, the solution of the problem had to be discarded.

Future Plans

During the following reporting period a null-system similar to that employed in the Swimmer Ordnance Locator Mark 9 Mod O will be evaluated. Such a system allows more degrees of freedom in design since the null coils and the search drive coil can be independently adjusted for optimum performance. If time permits an initial analysis of RF energy radiated from the above-water portion of the mine wire will be carried out.

Respectfully submitted,

F. L. Grismore

Arthur L. Bennett
Project Director

FLB/ALB/brj

H-93

GEORGIA INSTITUTE OF TECHNOLOGY

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ATLANTA, GEORGIA 30332

9 December 1966

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Department of the Navy
U. S. Navy Mine Defense Laboratory
Panama City, Florida

Attention: Dr. E. A. Hogge, Code 710

Subject: Monthly Progress Letter Report 6, Project A-937
"Scientific and Engineering Assistance on Mine Defense Problems"
Contract No. N600(24)-59885
Covering the Period October and November 1966

The work planned for this reporting period, outlined in Report No. 5, has been delayed; the needed manpower is expected on 15 December.

The specimen forwarded by MDL letter, Code 712/0662 of 25 November 1966 has been analyzed spectroscopically. The specimen was vaporized in the DC arc first at $2\frac{1}{2}$A and then at 5A. Examination of the spectra gives the following analysis:

Pb	very strong
Ag	weak ($< 10^{-5}$)
Ca	weak ($< 10^{-4}$)

Another sample was then run in the AC arc which emphasizes surface effects. The analysis is

Pb	strong
Si	trace
Ca	weak.

Respectfully submitted,

Arthur L. Bennett
Project Director

ALB:nmp